Spatial and Diel Variability in Photosynthetic and Photoprotective Pigments in Shallow Benthic Communities

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Award#: N000149710004

LONG-TERM GOALS

Our overall goal is to understand how photosynthetic and photoprotective pigments in benthic plants (primarily benthic microalgae) affect the optical properties (primarily spectral reflectance and fluorescence) of shallow benthic environments. The information gained will be used for the development and testing of rapid scanning optical techniques for detecting and assessing changes and specific disturbances in benthic communities.

OBJECTIVES

Our main objective is to determine the spatial and temporal (particularly diel) variation in a variety of photosynthetic and photoprotective pigments and examine how these pigments affect the spectral reflectance and fluorescence at the sediment surface. An understanding of these relationships is needed in order to refine algorithms used for processing data collected with various multispectral and hyperspectral imaging instruments used for identification and characterization of both living and man-made objects in shallow benthic environments.

APPROACH

During the May 1999 field session at Lee Stocking Island, Bahamas, replicate sediment cores were taken within a 0.5 meter square grid from eleven sampling sites and subenvironments within each site (Channel Marker ooid sand, thin grassy area, thick grassy area; Rainbow Gardens sand and grassy area; Twin Beaches mounds and film; North Perry; Normans Grapestone West (white and yellow grapestone areas). Our sampling was coordinated with that of Pam Reid and Eric Louchard who studied physical properties of the sediments and optical properties of the water column using a TSRB. Carol Stephens and Eric Louchard measured spectral reflectance in the laboratory at the surface of these cores using a tungsten halogen light source, RP200-7 reflection probe (illumination

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 1999		**00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE
Spatial and Diel Variability in Photosynthetic and Photoprotective Pigments in Shallow Benthic Communities

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Miami,Rosenstiel School of Marine and Atmospheric Science,4600 Rickenbacker Causeway,Miami,FL,33149

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT	b ABSTRACT	c THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

at 0^o angle), and a S2000-UV-VIS spectrometer. Radiance reflectance was calculated as the ratio of reflectance counts at the sediment surface to reflectance counts of a calibrated WS-1 Spectralon standard, multiplied by the reflectance of the standard (0.99).

Upon completion of the reflectance measurements, the top 5 mm of the core surfaces were removed and frozen in liquid nitrogen. Photosynthetic and photoprotective pigments were quantified by Carol Stephens using a Hewlett Packard 1100 series HPLC equipped with a diode-array detector. These pigment data were correlated with reflectance ratios at several wavebands specific for the major pigments observed (i.e. chlorophyll a, 674/700 nm; chlorophyll b, 654/700 nm; fucoxanthin, 534/700 nm; zeaxanthin, 458/700 nm.)

Larry Brand analyzed sediment surface spectral fluorescence using an Ocean Optics S2000-FL fiber optic fluorescence spectrometer with illumination by an Ocean Optics LS-450 blue LED. Chlorophyll fluorescence emission was measured between 651 and 715 nm. Many of the cores were incubated under running seawater in natural light and monitored for surface chlorophyll fluorescence over time to examine the diel variation in fluorescence that results from photoadaptation and vertical migration of microalgae in the sediments. Diel variation in fluorescence of phytoplankton in the water column of tanks where significant vertical migration could not occur was also monitored to distinguish between photoadaptation and vertical migration.

WORK COMPLETED

All samples for pigments from Lee Stocking Island and Monterey have been analyzed by HPLC and fluorometry. Most data on sediment surface reflectance and fluorescence have also been processed.

RESULTS

At Lee Stocking (May 1999), biomass of the benthic microalgae, as indicated by the mean chlorophyll a/cm^2 within a 0.5 meter square grid, ranged from <1 to almost 8 $\mu g/cm^2$, the highest being measured at North Perry and Normans (West) yellow Grapestone. Not only did biomass vary among sites and sub-environments, but it was quite variable within a 0.5 meter square grid (Fig. 1) at most sites. With the exception of one replicate from each of the Channel Marker sand and thin grass sites, both variability and amount of chlorophyll a/cm^2 were very similar to those measured within a mound at Twin Beaches. These latter environments were also characterized by the lowest biomass.

In addition to the spatial variability of benthic microalgal biomass, variability in community structure was indicated by variations in accessory pigment types and ratios (Fig.2). While the biomass at the Channel Marker sand and thin grass sites were similar to each other and to the Twin Beaches mound, the compositions of the benthic microalgae at those sites were different. At the Channel Marker sand site, no peridinin (indicator of dinoflagellates) was detected and the ratio of fucoxanthin/chlorophyll a was much lower than that at all of the other sites indicating that few diatoms were present. The highest zeaxanthin/chlorophyll a ratio was also found in the Channel Marker sand; this high ratio combined with the fact that no chlorophyll b or lutein (indicators of chlorophytes) were detected suggest that cyanobacteria dominate. Thus, this site is unique with respect to community structure. At the other sites high fucoxanthin/chlorophyll a ratios indicate that diatoms dominate.

The observed differences in benthic microalgal biomass and community structure both within and between sites have a profound effect of radiance reflectance spectra between 400-800 nm (Figs. 3 & 4). Radiance reflectance across the spectrum is inversely related to microalgal biomass (Chlorophyll a concentration). Reflectance at wavelengths specific for each pigment type is linearly related to the concentration of that pigment. For example, the regression coefficient of reflectance at 674/700 nm vs. Chlorophyll a = 0.97; 654/700 nm vs. chlorophyll b = 0.85; 534/700 nm vs. fucoxanthin = 0.88; 458/700 vs. zeaxanthin = 0.56.

Repeated measurements over time of chlorophyll fluorescence at the surface of incubated cores from various sites at Lee Stocking Island clearly indicate a strong diel variation, with much more fluorescence at dawn, dusk, and night than in the middle of the day (eg. Fig. 5). The fact that the fluorescence varies five to ten fold, much larger than diel variation in photoadaptation (eg. Fig. 6), suggests diel vertical migration of the microalgae as the major cause. It appears that the microalgae migrate to the surface of the sediment in dim or no light and migrate below the surface during the middle of the day to avoid photochemical damage.

IMPACT/APPLICATIONS

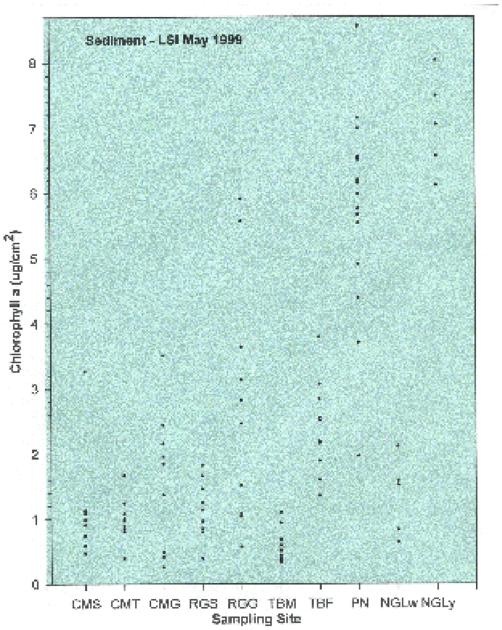
We have now directly linked our biological data with optical data collected by fiber optic probes positioned above the sediment surface. Our large scale spatial data comparing different ecological sites will be useful for characterizing different shallow benthic communities by remote sensing and detecting disturbances. Our small scale spatial variability will be useful for determining how to scale up from small patch size to remote sensing data with larger pixel sizes. Our diel data demonstrate that optical properties of sediments change on the time scale of hours because of the diel vertical migration of benthic microalgae. This must be taken into account when evaluating remote sensing data in shallow waters. To the extent that this vertical migration behavior is predictable, we hope to be able to evaluate and compare remote sensing data collected at different times of the day.

TRANSITIONS

The results of our field studies will be used by other members of the CoBOP team and other research and development programs within DOD concerned with remote sensing and underwater imaging of optically shallow water environments. Measurements of spatial and temporal variations in plant pigments from both sediments and water column will be used to refine relationships between measured benthic and water column optical properties and to understand how optical properties are affected by biological, chemical and physical processes. Our data show the importance of spatial and temporal biological variability not routinely considered by most remote sensing techniques.

RELATED PROJECTS

In a project funded by NOAA, we are examining the spatial and temporal distribution of benthic microalgae (estimated by chlorophyll concentrations) in Florida Bay and their relationship to nutrient and phytoplankton distributions.



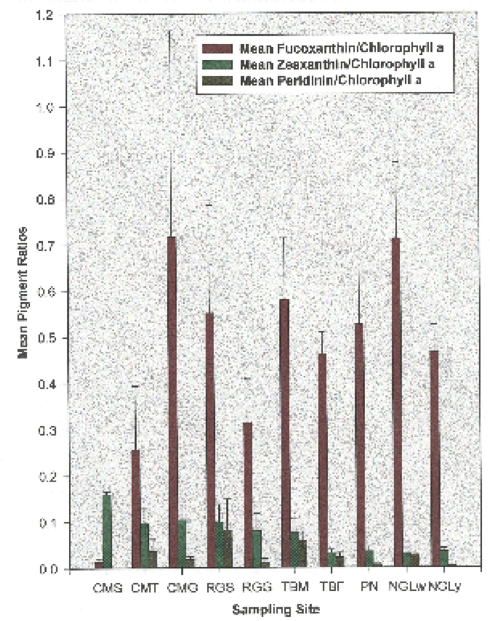
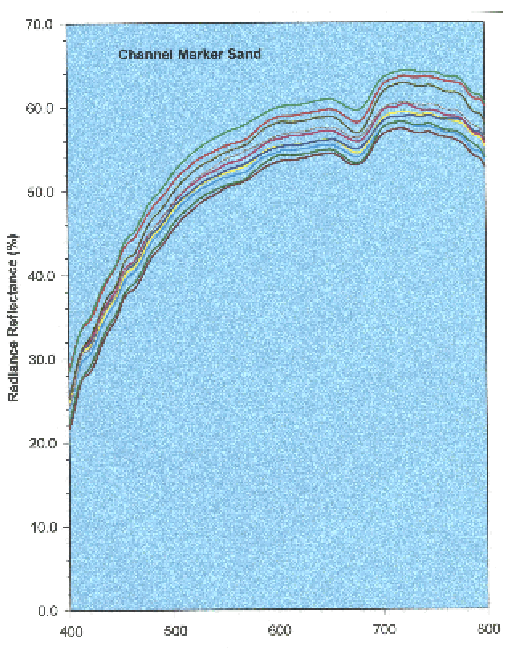


Fig. 1. Variability among sites and within 0.5 meter square grids at each site.

Fig. 2. Mean and standard deviation of ratios of major carotenoids to chlorophyll a at each sampling site.

Station Codes (x axis): CMS, Channel Marker sand; CMT, Channel Marker thin grass; CMG, Channel Marker thick Grass; RGS, Rainbow Gardens sand; RGG, RainBow Gardens grass; TBM, Twin Beaches mound; TBF, Twin Beaches film; PN, North Perry; NGLw, Norman's Grapestone (west) light-white; NGLy, Norman's Grapestone light-yellow.



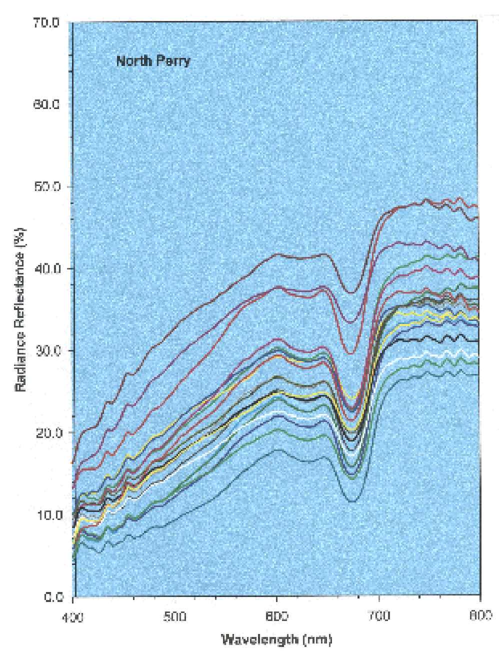


Fig. 3. Radiance Reflectance at surface of 10 cores from Channel Marker sand (Ooids) taken within 0.5 m. square grid.

Fig 4. Radiance Reflectance at surface of 19 cores from North Perry within 0.5 m. square grid.

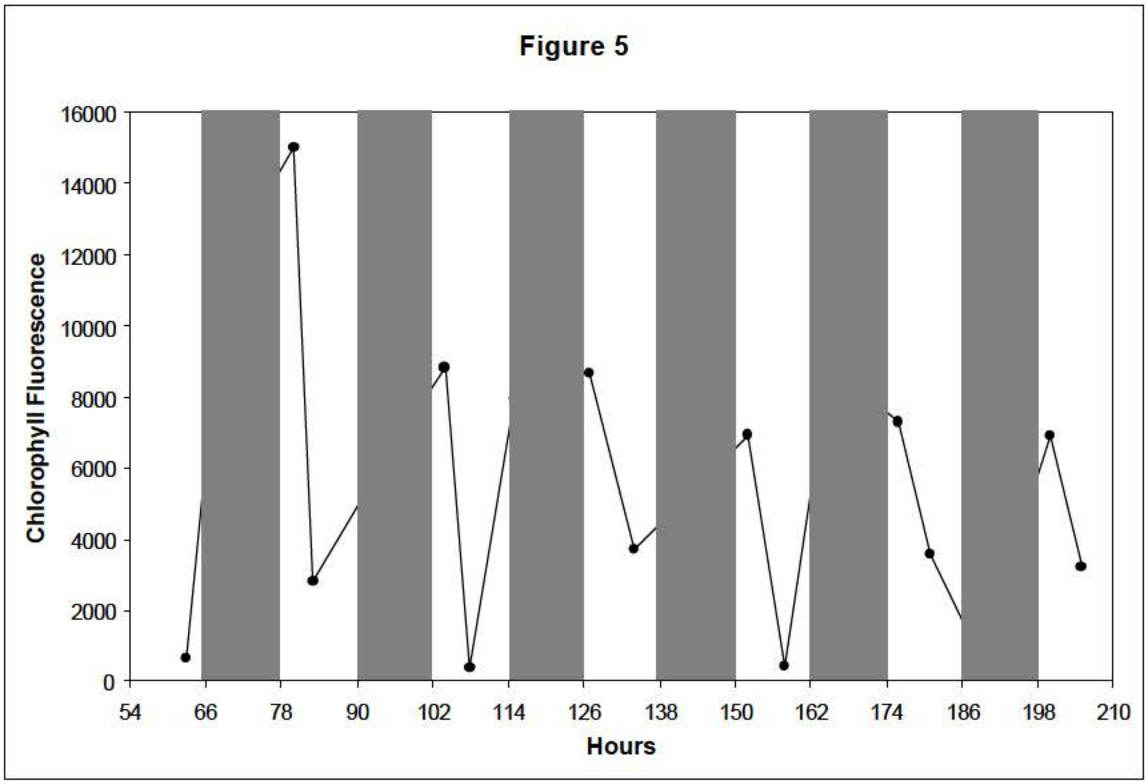


Figure 5
Chlorophyll Fluorescence
Hours
0
2000
4000
6000
8000
10000
12000
14000
16000
54
66
78
90
102
114
126
138
150
162
174
186
198
210

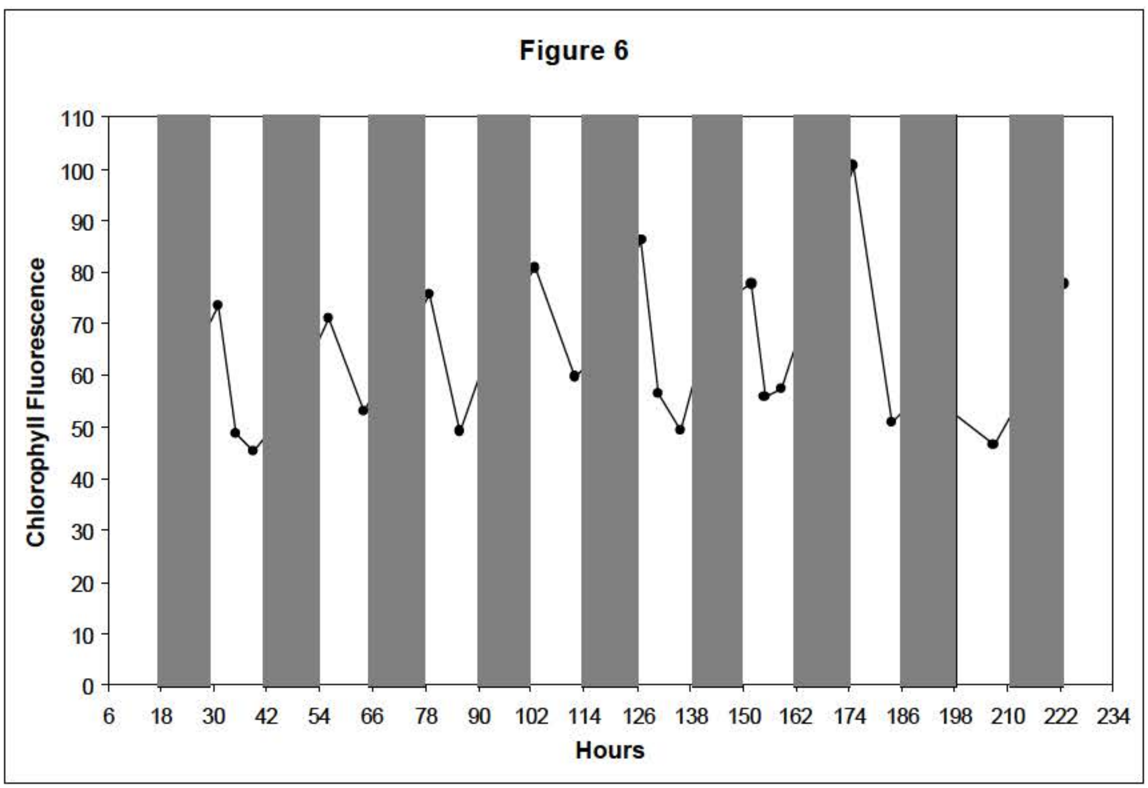


Figure 6
Chlorophyll Fluorescence
Hours
0
10
20
30
40
50
60
70
80
90
100
110
6
18
30
42
54
66
78
90
102
114
126
138
150
162
174
186
198
210
222
234